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Patentanmeldung Nr. Patent application No. Demande de brevet n°

00125776.5

Der Präsident des Europäischen Patentamts;
Im Auftrag

For the President of the European Patent Office

Le Président de l'Office européen des brevets
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Hatten

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Blatt 2 der Bescheinigung
Sheet 2 of the certificate
Page 2 de l'attestation

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Method for obtaining MRI-images using subsampling in a vertical field MRI-apparatus

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Method for obtaining MRI-images using sub-sampling in a vertical field MRI-apparatus

The invention relates to a method for obtaining MRI-images of an object to be examined in an imaging volume of an MRI-apparatus, the object having a longitudinal axis in the y-direction, wherein:

a homogeneous magnetic field in the imaging volume of the apparatus is provided in the z-direction,

the object to be examined is positioned in the imaging volume such that its longitudinal axis is transverse to the z-direction,

an RF excitation pulse in the imaging volume of the apparatus is generated,

magnetic resonance signals which are due to the RF excitation pulse are acquired by means of at least one RF receiving coil.

Such a method is known from an article in the ISMRM Book of Abstracts 1999, page 736, "Vertical Field Open RF Body Coils". In the article a Vertical Field Open MRI-system is described in which a vertical homogeneous magnetic main field is generated between two parallel magnet poles having horizontal pole faces. The direction of the homogeneous field (the B_0 field) is indicated as the z-direction. During examination an object to be examined, in medical MRI-apparatus being a patient, is lying horizontally between the pole faces. The longitudinal direction of the patient (head-to-feet) is indicated as the y-direction; the direction perpendicular to the z- and the y-direction is indicated as the x-direction. According to the well known MRI-imaging process a radio frequency (RF) excitation pulse in the imaging volume of the apparatus is produced, that generates magnetisation of the material in the imaging volume. After the RF excitation has been removed the magnetisation vector is precessing about the B_0 field lines at the Larmor frequency, thus causing RF magnetic resonance signals that can be received by RF receiving coils.

In general the RF magnetic resonance signals that are received by the receiving coils are further processed for reconstructing the desired MRI-image. A step in said processing is sampling the received signals, this step being the speed limiting factor in the

process of obtaining the MRI-image. In order to enhance said is speed it is known to apply sub-sampling of the received signals in the so-called K-space. An example of such sub-sampling technique is known by the name of SENSE. In said article in the ISMRM Book of Abstracts it is known to use a butterfly coil in combination with a vertical magnetic field.

Combining a vertical homogeneous magnetic main field in an MRI-system with said sub-sampling techniques provides the advantages of both kinds of systems, avoiding the claustrophobia sensations of the patient by offering an open (vertical field) system and obtaining a high speed imaging process by sub-sampling.

The invention has for its object to provide an MRI-imaging method applying an RF receive coil arrangement making said high speed imaging by sub-sampling possible in a vertical field MRI-apparatus. To achieve this the method according to the invention is characterized in that the magnetic resonance signals which are due to the RF excitation pulse are acquired in a sub-sampled fashion by means of a set of at least two RF receiving coils,

a magnetic resonance image is derived from the sub-sampled magnetic resonance signals and on the basis of previously determined spatial coil sensitivity profiles of each RF coil in the set of RF receiving coils, which spatial coil sensitivity profiles are mutually independent, and

the planes of the at least two receiving coils are substantially mutually parallel and parallel to the z-direction.

The invention is based on the application of an sub-sampling technique known per se in a vertical field MRI-apparatus. Such sub-sampling techniques are known per se by the names of SENSE or SMASH. Such techniques address the problem of fast acquiring MRI-signals.

The time required for acquisition of the MRI-signals is reduced by employing sub-sampling of the MR-signals. Such sub-sampling involves a reduction in k-space of the number of sampled points which can be achieved in various ways. Notably, the MR signals are picked-up through signal channels pertaining to several receiver coils, preferably surface coils. Acquisition through several signal channels enables parallel acquisition of signals so as to further reduce the signal acquisition time. Owing to the sub-sampling, sampled data contain contributions from several positions in the object being imaged. The MR image is reconstructed from the sub-sampled MR-signals with the use of a sensitivity profile associated with the signal channels. Notably, the sensitivity profile is for example the spatial

sensitivity profile of the receiver antennae, such as receiver coils. Preferably, surface coils are employed as the receiver antennae. The reconstructed magnetic resonance image may be considered as being composed of a large number of spatial harmonic components which are associated with brightness/contrast variations at respective wavelengths. The resolution of the magnetic resonance image is determined by the smallest wavelength, that is by the highest wavenumber (k-value).The largest wavelength, i.e. the smallest wavenumber, involved, is the field-of-view (FOV) of the magnetic resonance image. The resolution is determined by the ratio of the field-of-view and the number of samples.

The sub sampling may be achieved in that respective receiver antennae acquire MR signals such that their resolution in k-space is coarser than required for the resolution of the magnetic resonance image. The smallest wavenumber sampled, i.e. the minimum step-size in k-space, is increased while the largest wavenumber sampled is maintained. Hence, the image resolution remains the same when applying sub-sampling, while the minimum k-space step increases, i.e. the FOV decreases. The sub-sampling may be achieved by reduction of the sample density in k-space, for instance by skipping lines in the scanning of k-space so that lines in k-space are scanned which are more widely separated than required for the resolution of the magnetic resonance image. The sub-sampling may be achieved by reducing the field-of-view while maintaining the largest k-value so that the number of sampled points is accordingly reduced. Owing to the reduced field-of-view sampled data contain contributions from several positions in the object being imaged.

Notably, when receiver coil images are reconstructed from sub-sampled MR-signals from respective receiver coils, such receiver coil images contain aliasing artefacts caused by the reduced FOV. From the receiver coil images and the sensitivity profiles the contributions in individual positions of the receiver coil images from different positions in the image are disentangled and the magnetic resonance image is reconstructed. This MR-imaging method is known as such under the acronym SENSE-method. This SENSE-method is discussed in more detail in an article entitled "SENSE: Sensitivity Encoding for Fast MRI", Magnetic Resonance in Medicine 42: 952-962 (1999).

Sub-sampling may also be carried-out spatially. In that case the spatial resolution of the MR-signals is less than the resolution of the MR-image and MR-signals corresponding to a full resolution of the MR-image are formed on the basis of the sensitivity profile. Spatial sub-sampling is in particular achieved in that MR-signals in separate signal channels, e.g. from individual receiver coils, form a combination of contributions from several portions of the object. Such portions are for example simultaneously excited slices.

Often the MR-signals in each signal channel form linear combinations of contributions from several portions, e.g. slices. This linear combination involves the sensitivity profile associated with the signal channels, i.e. of the receiver coils. Thus, the MR-signals of the respective signal channels and the MR-signals of respective portions (slices) are related by a sensitivity matrix which represents weights of the contribution of several portions of the object in the respective signal channels due to the sensitivity profile. By inversion of the sensitivity matrix, MR-signals pertaining to respective portions of the object are derived. In particular MR-signals from respective slices are derived and magnetic resonance images of these slices are reconstructed.

In order to apply the sub-sampling technique it is thus necessary to provide for at least two RF receiving coils of which the spatial coil sensitivity profiles are known. In order to make the reconstruction of the MR-image possible these profiles should be mutually independent.

According to the invention it has been found that it is possible to apply a sub-sample technique in a vertical field MRI-apparatus by providing at least RF receiving coils, the planes of being substantially mutually parallel and parallel to the z-direction. By applying this arrangement of RF coils it is possible to obtain the required RF signals while not hindering patient access to the imaging volume.

In a preferred embodiment the receiving coils are embodied as butterfly coils. Butterfly coils are known per se. As is well known such are sensitive for magnetic fields that are parallel to the coil plane which makes these coils in particular suitable for the use in vertical field MRI-apparatus. The name "butterfly coil" is derived from an often used shape of the coil windings. It should however be noted that within the framework of the invention each RF receiving coil being sensitive to RF fields parallel to their coil plane is indicated as "butterfly coil".

In a still further preferred embodiment the butterfly coils are sensitive to an RF field component transverse to the z-direction. By means of this measure the coils can be positioned over and under the patient thus leaving making access to the patient possible and also giving the possibility of moving the patient in and out of the imaging volume while not hindering him or her by the RF coils.

Further embodiments are claimed in the sub-claims. These embodiments and their technical effects will be described with reference to the figures.

The invention and its advantages will be explained in detail with reference to the drawing, in which identical reference numbers refer to the same elements. Therein:

Figure 1 : shows an overview of a known vertical field apparatus for obtaining MRI-images;

Figures 2a, 2b and 2c : RF butterfly coil arrangements according to a preferred embodiment of the invention;

Figure 3 : an RF butterfly coil arrangement having multiple sensitivity directions according to the invention;

Figures 4a, 4b and 4c : RF butterfly coil arrangements according to another embodiment of the invention;

Figure 5 : a coil arrangement according to another embodiment of the invention consisting of butterfly coils and single coils;

Figure 6 : another coil arrangement according to invention consisting of butterfly coils and single coils;

Figure 7 : another coil arrangement according to invention consisting of more butterfly coils and more single coils;

Figure 1 shows a known vertical field apparatus for obtaining MRI-images. A co-ordinate system showing the various co-ordinates is drawn on top of the apparatus to indicate the various co-ordinate directions in relation to the apparatus. The apparatus is provided with a stand 2 for carrying the lower magnet pole 4 and the upper magnet pole 6. It should be remarked that the expression "magnet pole" means the aggregate of corresponding coils for generating the main magnetic field in the z-direction without the necessity (but maintaining the possibility) that an iron circuit is provided for conducting the magnetic flux from one pole to the other. Between the magnet poles there is a space for positioning the patient 8 to be examined. The patient is lying on a table top 14 that in turn is carried by a support that is part of the stand 2 such that the patient 8 can be positioned in the required position and orientation (in the y-direction) between the magnet poles 4 and 6. The longitudinal direction of the patient (head-to-feet) is the y-direction.

In customary MRI-apparatus the space for receiving the patient to be examined is tunnel shaped being in the order of magnitude of 60 cm which causes sensations of fear and claustrophobia with many patients, in particular with children. It is an advantage of the constellation of magnet poles according to figure 1 that the patient during positioning

in such apparatus keeps an ample view on the scenery thus avoiding said sensations completely or in part.

At the patient's side the magnet poles are confined by pole surfaces 10 and 12, which pole surfaces are constituted by the encapsulation cover of the cryo containers in which the superconducting magnet coils reside. The distance between the pole surfaces is chosen in such a way that said unpleasant sensations of the patient are counteracted, but not that large that the production of the magnet poles becomes to costly. In practice a distance between 50 and 60 cm appears to be a suitable value.

Figures 2a, 2b and 2c each show an RF butterfly coil arrangement according to a preferred embodiment of the invention. These figures show some of the basic two coil (two channel) arrangements that are compatible with a vertical field magnet. A co-ordinate system showing the various co-ordinates is drawn on top of the figure to indicate the various co-ordinate directions in relation to the coils.

Figure 2a shows two butterfly coils 20-1 and 20-2 which can be placed anterior and posterior to the patient. In this case the coils are most sensitive to the x-component of transverse magnetization.

Figure 2b shows the same arrangement but rotated by 90 degrees around the B_0-axis (z-axis) to provide most sensitivity to the M_y component. The fact that both coil elements 20-3 and 20-4, anterior and posterior, see the same imaging volume, but with oppositely facing sensitivity profile makes them ideal for sub-sampling applications like SENSE using a scan time reduction factor of up to 2.

Figure 2c shows another possibility using butterfly coils 20-5 and 20-6 left and right (L/R configuration) of the patient to provide sensitivity to the y-component of transverse magnetization. Again the opposing sensitivity profiles of the two coils provides and ideal configuration for SENSE applications using a scan time reduction factor of up to 2. This configuration provides sensitivity to the y-component of the RF-field also.

Figure 3 shows a further embodiment that combines 4 (linear) butterfly coil elements 30-1, 30-2. 30-3 and 30-4 to form 2 channel quadrature coil arrangements for a 2 times reduction factor in SENSE. Or, alternatively, each of the 4 linear elements can be otherwise distributed to provide 4 channel linear coil arrangements that allow a 2 times reduction factor in SENSE along two orthogonal spatial axes, thereby enabling a 4 times SENSE reduction factor in total. The arrangement has the further advantage that the patient is accessible from the y-direction as well as from the x-direction. There are no RF-coils that form an obstruction for the patient to be positioned in the imaging volume.

Figures 4a, 4b and 4c also show embodiments that combine 4 butterfly coil elements to form 2 channel quadrature coil arrangements for a 2 times reduction factor in SENSE. Also, alternatively, each of the 4 linear elements can be otherwise distributed to provide 4 channel linear coil arrangements that allow a 2 times reduction factor in SENSE along two orthogonal spatial axes, thereby enabling a 4 times SENSE reduction factor in total. In the case of the embodiment of figure 4a the coils 40-1 and 40-2 are most sensitive to the x-component of transverse magnetization (RF field). In the case of the embodiment of figure 4b the coils 40-3 and 40-4 are most sensitive to the y-component of transverse magnetization. Also in the case of the embodiment of figure 4c the coils 40-5 and 40-6 are most sensitive to the y-component of transverse magnetization. It is also possible to combine the various embodiments of figures 2a, 2b and 2c to obtain a corresponding 2 times reduction factor in SENSE along two orthogonal spatial axes, thereby enabling a 4 times SENSE reduction factor in total.

Figure 5 shows an embodiment that combines two butterfly coils 50-1 and 50-2 with two single coils 50-3 and 50-4. Just like the embodiments of figures 3 and 4 a combination of 4 linear elements forms a 2 channel quadrature coil arrangement to obtain a 2 times reduction factor in SENSE. The butterfly coils 50-1 and 50-2 are most sensitive to the y-component of transverse magnetization (RF field), whereas the single coils 50-3 and 50-4 are most sensitive to the x-component of the RF field.

Figures 6 and 7 show further embodiments using even more channels and combinations of linear and quadrature coil elements that enable even higher reduction factors for SENSE applications as well as extended spatial coverage.

In Figure 6 the arrangement of Figure 4a (coils 60-1, 60-2, 60-3 and 60-4) is combined with two single coils 60-5 and 60-6. The butterfly coils are most sensitive to the x-component of the RF field just like the single coils 50-3 and 50-4.

In Figure 7 the arrangement of Figure 3 (coils 70-1 and 70-2) is combined with the arrangement of Figure 5 (coils 70-3 and 70-4) as well as with two single coils 70-5 and 70-6. The butterfly coils 70-1 and 70-2 are most sensitive to the x-component and to the y-component of the RF field; the butterfly coils in coil sets 70-3 and 70-4 are most sensitive to the y-component of the RF field. The single coils in coil sets 70-3 and 70-4 are most sensitive to the x-component of the RF field. The single coils 70-5 and 70-6 are most sensitive to the y-component of the RF field.

It should be remarked that in the SENSE application individual coil elements are not required to be physically overlapping, contrary to the case of the well known phased

array coils. Though the coil elements in the various Figures are depicted as square or rectangular rigid coils, thy can also be circular or otherwise non-square and flexible. In the case of the butterfly elements it is also possible to substitute these elements with coils that exhibit similar properties of sensitivity with respect to magnetization components parallel to the plane of the coil. In the case where simple loop (single loop) and butterfly elements overlap to generate a quadrature element it should be understood that this can also be substituted by a single quadrature coil element that is sensitive to both components of the transverse magnetization. In the case where two butterfly elements overlap with a 90 degree rotation to generate a quadrature element it should be understood that this can also be substituted by a single quadrature coil element that is sensitive to both components of the transverse magnetization. The coils as shown in the various Figures coils can be used for both RF transmission and reception.

CLAIMS:

1. A method for obtaining MRI-images of an object (8) to be examined in an imaging volume of an MRI-apparatus, the object having a longitudinal axis in the y-direction, wherein:

a homogeneous magnetic field in the imaging volume of the apparatus is provided in the z-direction,

the object to be examined (8) is positioned in the imaging volume such that its longitudinal axis is transverse to the z-direction,

an RF excitation pulse in the imaging volume of the apparatus is generated,

magnetic resonance signals which are due to the RF excitation pulse are acquired by means of at least one RF receiving coil,

characterized in that

the magnetic resonance signals which are due to the RF excitation pulse are acquired in a sub-sampled fashion by means of a set of at least two RF receiving coils (20),

a magnetic resonance image is derived from the sub-sampled magnetic resonance signals and on the basis of previously determined spatial coil sensitivity profiles of each RF coil in the set of RF receiving coils (20), which spatial coil sensitivity profiles are mutually independent, and

the planes of the at least two receiving coils are substantially mutually parallel and parallel to the z-direction.

2. A method as claimed in Claim 1 in which the receiving coils are embodied as butterfly coils.

3. A method as claimed in Claim 2 in which the butterfly coils are sensitive to an RF field component transverse to the z-direction.

4. A method as claimed in Claim 3 in which two further butterfly coils (40-1, 40-2) are provided such that each time two butterfly coils lie in the same coil plane next to each other and all coils are sensitive to the same RF field component.

5. A method as claimed in Claim 3 in which two further butterfly coils (30-2, 30-4) are provided such that each time one further butterfly coil (30-2) is concentrically arranged to one butterfly coil (30-1) of said set of at least two RF receiving coils, the one further butterfly coil and the one butterfly coil of said set of at least two RF receiving coils are lying in the same coil plane, and which further butterfly coils are sensitive to an RF field component which is transverse to the RF field component to which the butterfly coils of said set are sensitive.

6. A method as claimed in Claim 4 in which two single coils (60-5, 60-6) are provided having mutually parallel coil planes which single coils are arranged in such a way that their coil planes are transverse to the planes of the butterfly coils (60-1, 60-2, 60-3, 60-4).

7. A method as claimed in Claim 5 in which

* a first set of single coils (70-7, 70-8) is provided which single coils have mutually parallel coil planes and which are arranged in such a way that their coil planes are transverse to the planes of the butterfly coils (70-1, 70-2),

* a second set of single coils (70-5, 70-6) is provided which single coils have mutually parallel coil planes and which are arranged in such a way that their coil planes are transverse to the planes of the butterfly coils (70-1, 70-2) as well as to the planes of the first set of single coils (70-7, 70-8), and

* a further set of butterfly coils (70-3, 70-4) is provided such that each time one further butterfly coil (70-3, 70-4) is concentrically arranged to one single coil (70-8, 70-7) of said first set, which coils are lying in the same coil plane.

8. A method as claimed in Claim 3 in which two single coils (50-3, 50-4) are provided such that a first one and a second one of the single coils is concentrically arranged to a first one and a second one of the butterfly coils (50-1, 50-2), respectively which first coils are lying in the same coil plane as well as the second coils.

ABSTRACT:

The invention relates to a method for obtaining MRI-images in a vertical main field using a sub-sampling scheme like SENSE. According to the invention a number of coil arrangements have been proposed, such that the advantages of SENSE (high speed acquisition) and vertical field (ample view for the patient to avoid sensations of fear and claustrophobia) are retained. The coil arrangements contain preferably butterfly coils, and they are arranged in such a way that they make access to the patient possible and also give the possibility of moving the patient in and out of the imaging volume while not hindering him or her by the RF coils.

Figure 7.

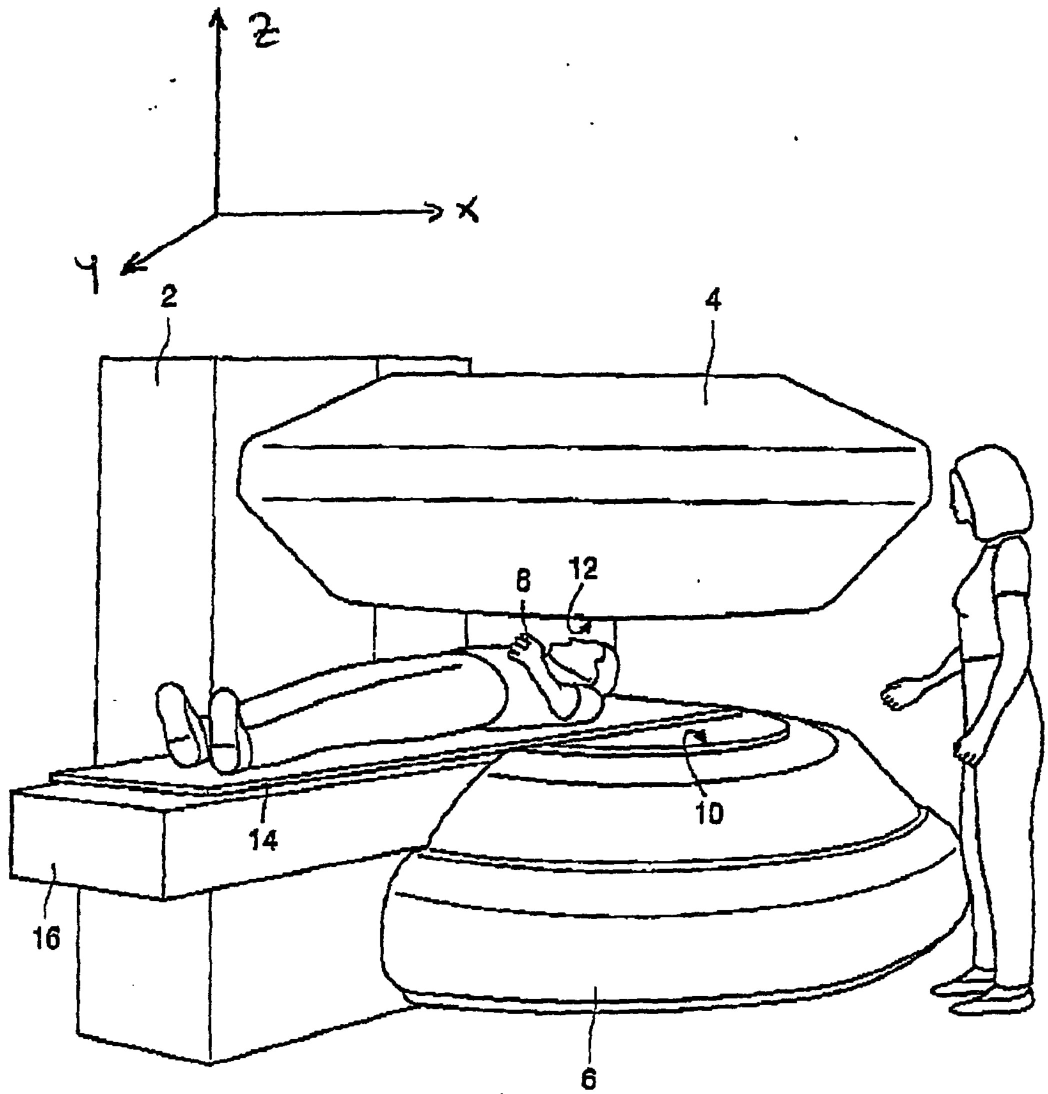

FIG. 1

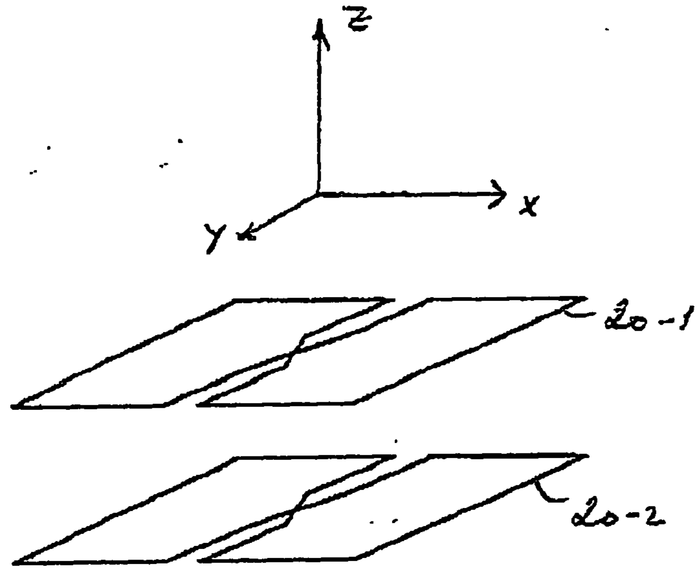

Fig. 2a

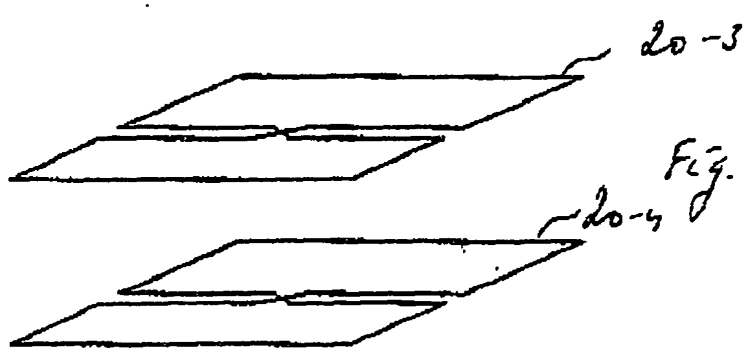

Fig. 2b

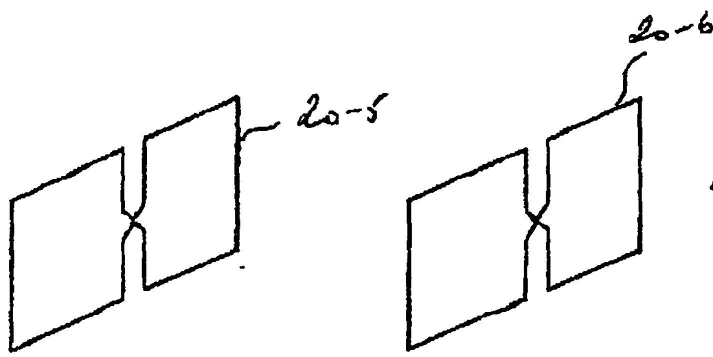

Fig. 2c

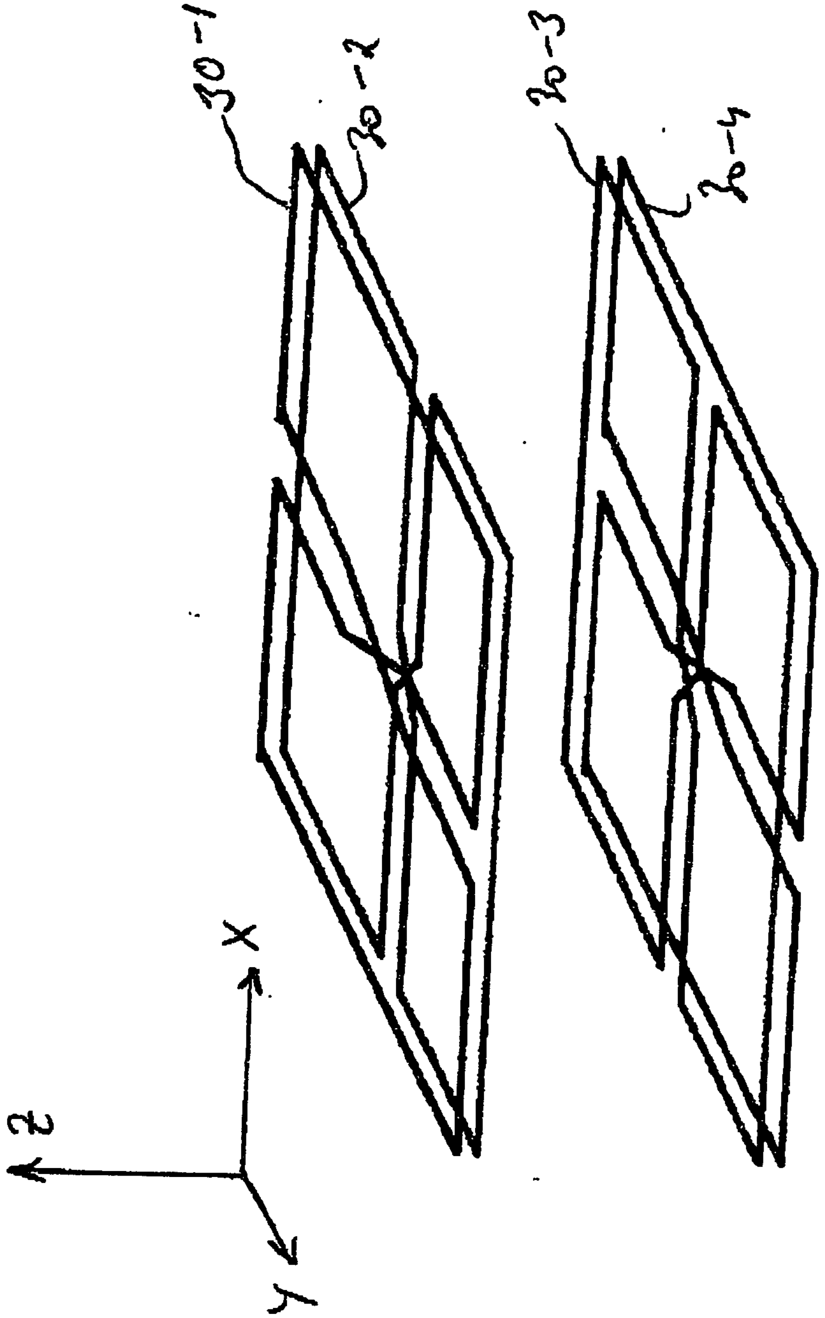

Fig. 3

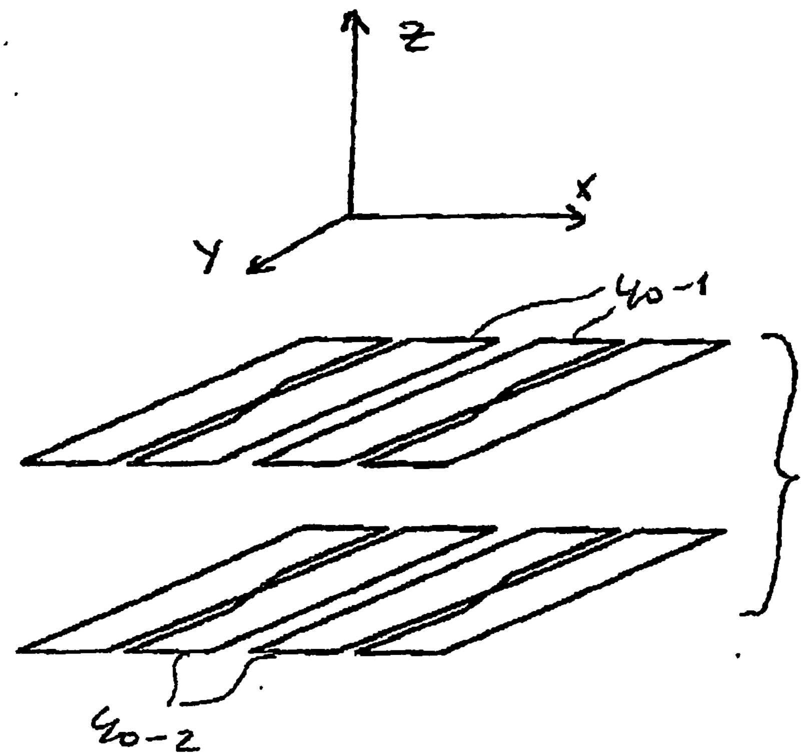

Fig. 4a

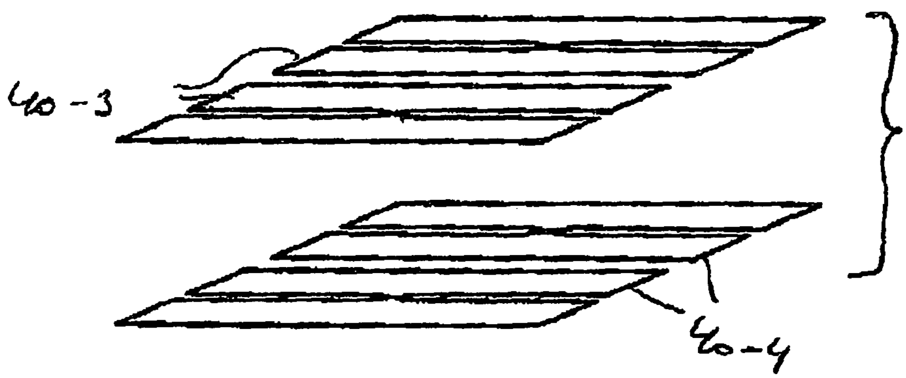

Fig. 4b

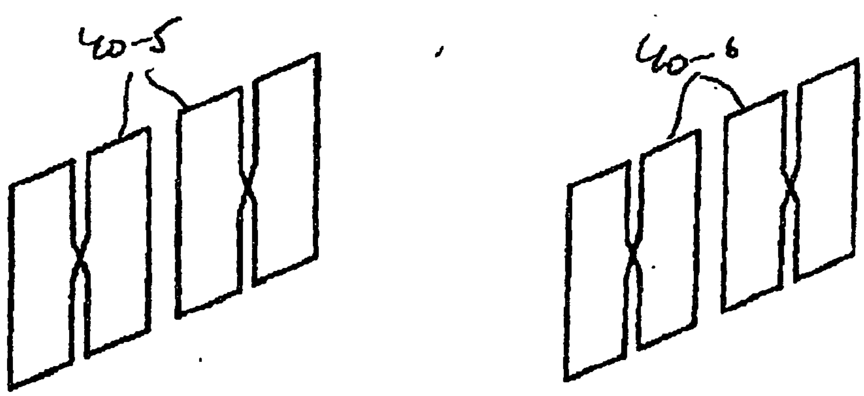

Fig. 4c

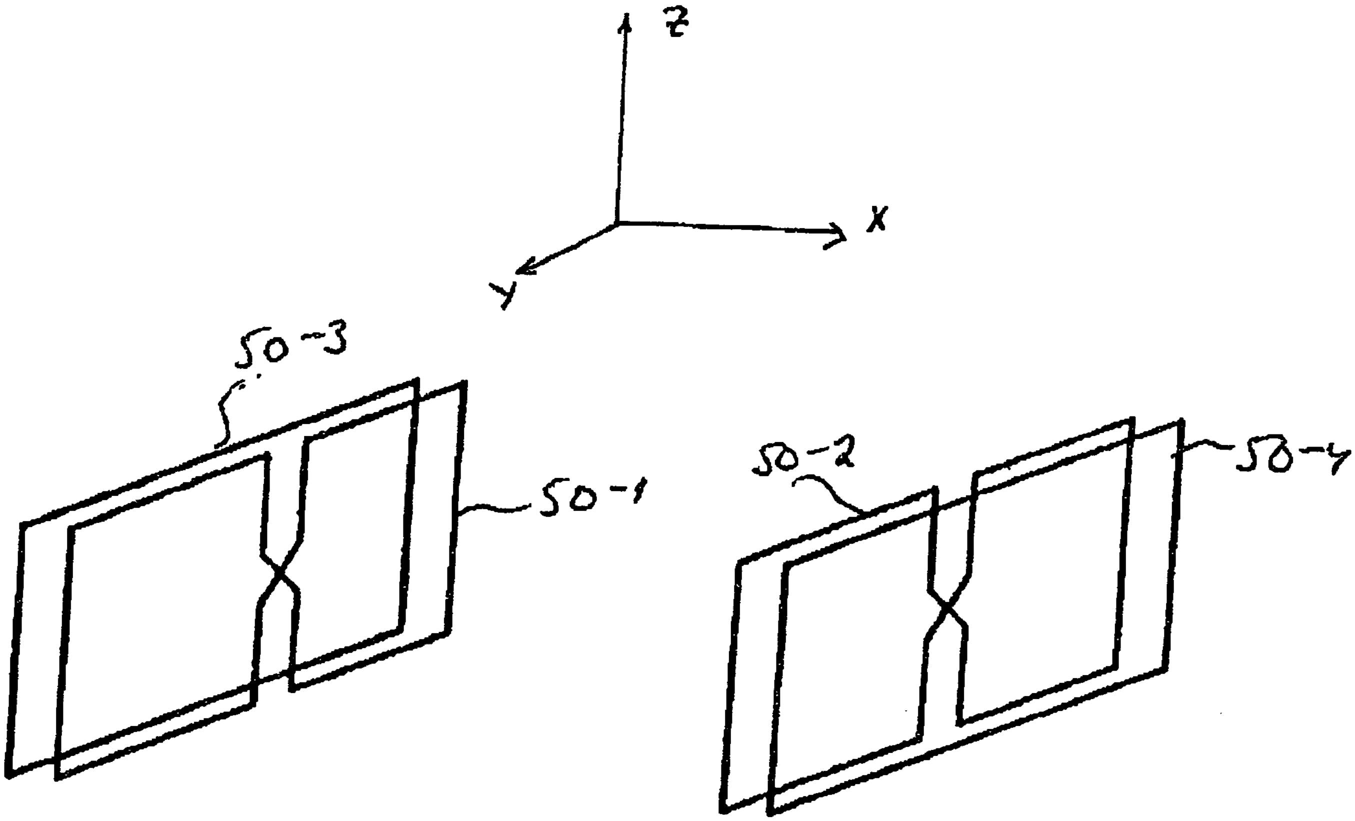

Fig. 5

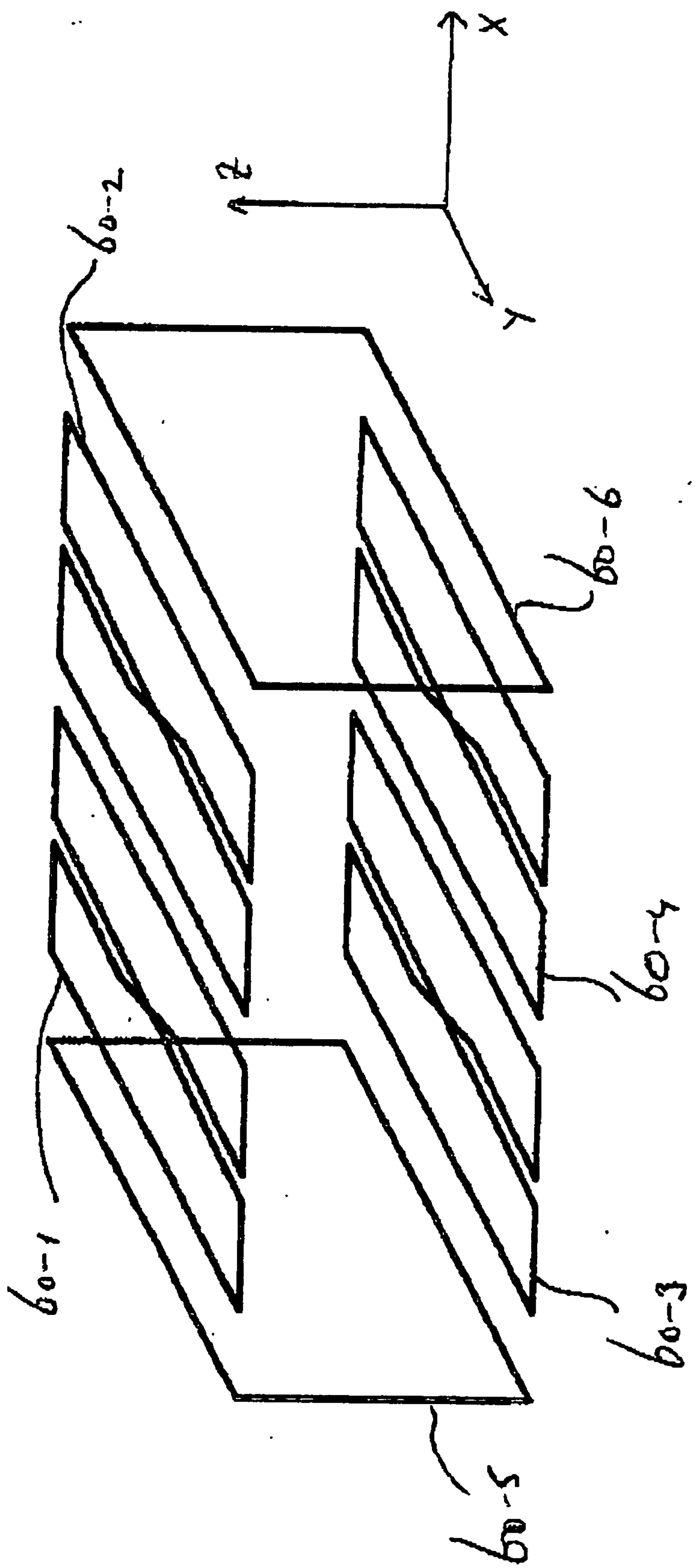

Fig. 6

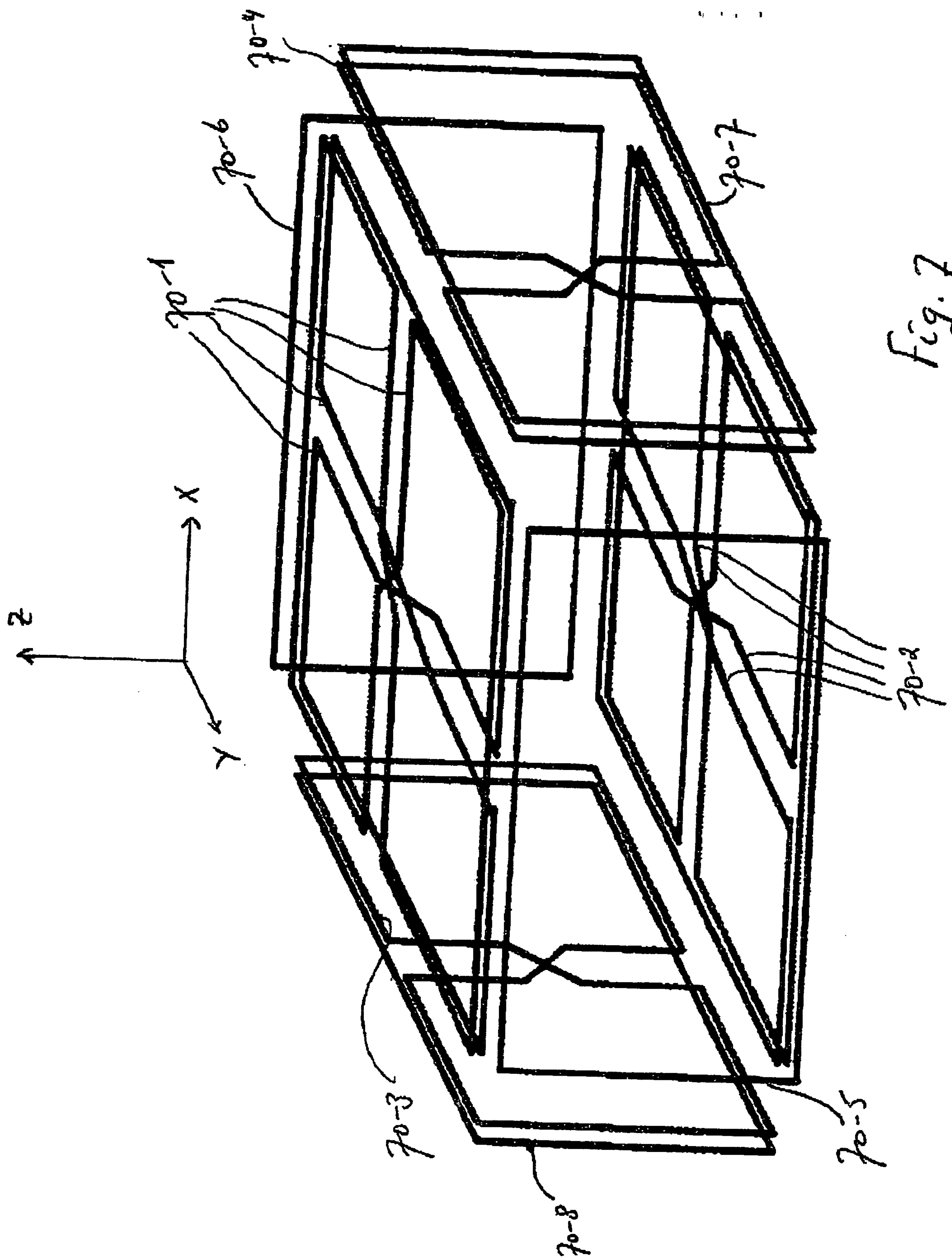

Fig. 7